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CDM 2.Ø -- CLIMATOLOGICAL DISPERSION MODEL
User's Guide
(Abridged)

by

John S. Irwin
Meteorology and Assessment Division
Atmospheric Sciences Research Laboratory
Research Triangle Park, NC 27711

and

Thomas Chico and Joseph Catalano
Aerocomp, Inc.
3303 Harbor Boulevard
Costa Mesa, CA 92626

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Project Officer

D. Bruce Turner
Meteorology and Assessment Division
Atmospheric Sciences Research Laboratory
Research Triangle Park, NC 27711

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ATMOSPHERIC SCIENCES RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U. S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

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DISCLAIMER

The original report, of which this is an abridgement, was reviewed by the Atmospheric Sciences Research Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U. S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

AFFILIATION

Mr. John S. Irwin is a meteorologist in the Meteorology and Assessment Division, Environmental Protection Agency, Research Triangle Park, North Carolina. He is on assignment from the National Oceanic and Atmospheric Administration, U. S. Department of Commerce. Mr. Joseph A. Catalano is the technical director of Aerocomp, Inc., Costa Mesa, California and Mr. Chico is a research meteorologist there.

PREFACE TO THE ABRIDGED VERSION

This abridged version of the CDM-2.0 User's Guide has been created for users of the Support Center for Regulatory Air Models (SCRAM) website. The availability of this and other model user's guides on the SCRAM website will facilitate the immediate use of models which have been downloaded from the SCRAM website, without having to wait for delivery of the complete user's guide.

Although some portions of the User's Guide have been omitted to save space, nothing was omitted that is needed by the user to run the model. Nevertheless, the user is strongly encouraged to obtain the complete user's guide from NTIS. NTIS Document Numbers for model user's guides can be found on the SCRAM website on the User’s Guide webpage under NTIS Availability.

Note that the actual page numbers in your copy of the document may differ from those indicated in the Table of Contents, depending on the kind of printer (as well as the available type font) that is used to print your copy of this document.

This abridged version of the CDM-2.0 User's Guide was composed by Computer Sciences Corporation, RTP, North Carolina.

PREFACE TO THE ORIGINAL USER'S GUIDE

One area of research within the Meteorology and Assessment Division is development, evaluation, validation, and application of models for air quality simulation, photochemistry, and meteorology. The models must be able to describe air quality and atmospheric processes affecting the dispersion of airborne pollutants on scales ranging from local to global. Within the Division, the Environmental Operations Branch adapts and evaluates new and existing meteorological dispersion models and statistical technique models, tailors effective models for recurring user application, and makes these models available through EPA's User's Network for Applied Modeling of Air Pollution (UNAMAP) system.

CDM-2.0 estimates long-term nonreactive pollutant concentrations using average emission rates from point and area sources and a joint frequency distribution of wind direction, wind speed, and stability.

Although attempts are made to thoroughly check computer programs with a wide variety of input data, errors are occasionally found. Revisions may be obtained as they are issued by completing and returning the form on the last page of this guide.

The first four sections of this document are directed to managers and project directors who wish to evaluate the applicability of the model to their needs. Sections 5, 6, and 10 are directed to engineers, meteorologists, and other scientists who are required to become familiar with the details of the model. Finally, Sections 7 through 10 are directed to persons responsible for implementing and executing the program.

Comments and suggestions regarding this publication should be directed to:

> Chief, Environmental Operations Branch
> Meteorology and Assessment Division (MD-80)
> Environmental Protection Agency
> Research Triangle Park, NC 27711.

Technical questions regarding use of the model may be asked by calling (919) 541-4564. Users within the Federal Government may call FTS 629-4564. Copies of the user's guide are available from the National Technical Information Service (NTIS), Springfield, VA 22161.

SYMBOLS AND ABBREVIATIONS

Where: m = mass, l = length, t = time, K = temperature

a, b, c	=	constants in dispersion parameter equations
A, B	=	calibration constants (i.e., intercept and slope, respectively)
$\overline{C}_A$	=	average concentration from area sources (m/l^3)
$\overline{C}_P$	=	average concentration from point sources (m/l^3)
D_s	=	stack inside diameter (l)
f	=	stack-tip downwash correction factor
f_e	=	fraction of the input area-source height that represents the physical height
F	=	buoyancy flux parameter (l^4/t^3)
Fr	=	Froude number
g	=	acceleration due to gravity (l/t^2)
G_n	=	emission rate of nth point source (m/t)
h	=	physical stack height (l)
h'	=	stack height adjusted for Briggs stack-tip downwash (l)
H	=	effective stack height (l)
H_a	=	input area source height (physical height plus assumed effluent rise with a 5 m/sec wind speed) (l)
k	=	index identifying the wind-direction sector
k_n	=	wind sector appropriate for nth point source
R	=	index identifying the wind-speed class

L	= mixing height (l)
m	= index identifying the stability category
n	= number of point sources
N	= number of wind-direction sectors
p	= wind-profile exponent
p_a	= atmospheric pressure (m/lt^2)
P_m	= stability class
Q(D,2)	= area source emission rate per unit area (m/tl^2)
q_k(D)	= IQ(D,2)d2 (m/t)
s	= stability parameter (t^{-2})
S(D,z;U_R,P_m)	= dispersion function
$T_{1/2}$	= pollutant half-life (t)
T_a	= ambient air temperature (K)
T_s	= stack gas exit temperature (K)
U	= wind speed at stack height (l/t)
U_R	= representative wind speed (l/t)
V_s	= stack gas exit velocity (l/t)
x_f	= distance to final rise (l)
x^*	= distance at which atmospheric turbulence begins to dominate entrainment (l)
X, Y	= axes of the grid system; X-axis points east and Y-axis points north
z	= height of receptor above ground level (l)
)H	= plume rise (l)

M2/Mz = vertical potential temperature gradient of a layer of air (K/l)

2 = angle relative to polar coordinates centered on receptor (radians)

D = distance from receptor to source (l)

D_n = distance from receptor to nth point source (1)

F_z = vertical dispersion parameter (l)

F_{zb} = buoyancy-induced vertical dispersion (l)

F_{ze} = effective vertical dispersion (l)

N(k,R,m) = meteorological joint frequency function

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Support of Aerocomp by the Environmental Protection Agency Contract Nos. 68-02-3750 and 68-02-4106 is also gratefully acknowledged.

EXECUTIVE SUMMARY

CDM-2.0 (Climatological Dispersion Model - Version 2.0) determines long-term (seasonal or annual) pollutant concentrations in a rural or urban setting using average emission rates from point and area sources and a joint frequency distribution of wind direction, wind speed, and stability. The algorithm is based on Gaussian plume assumptions and is thus subject to the limitations of non-reactive pollutants and a homogeneous wind field. Terrain in the modeling region is assumed to be level or gently rolling. Computations can be made for up to 200 point sources and 2500 area sources at an unlimited number of receptor locations.

CDM-2.0 is an enhanced version of CDM. The enhancements of CDM-2.0 give the user added flexibility to tailor technical features of the model to particular source-receptor configurations and locales. The joint-frequency function describing the meteorology can be specified using either a 16-point or a 36-point compass for the wind sectors. The initial dispersion for point sources can be computed as either a building effect (affecting dispersion from sources with stack heights below 50 m), as a buoyant plume rise effect (described by Pasquill, 1976), or both. Provision has been made to allow estimation of the effects of stack downwash on the plume rise using either of two algorithms--Briggs (1974) or Bjorklund and Bowers (1982). The user has the option of choosing among seven schemes for characterizing vertical dispersion downwind of the source. Added to the dispersion algorithm used by CDM (Busse and Zimmerman, 1973) are the following schemes:

- Briggs--rural (Gifford, 1976),
- Briggs--urban (Gifford, 1976),
- Brookhaven National Laboratory (Singer and Smith, 1966),
- Klug (Vogt, 1977),
- St. Louis (Vogt, 1977), and
- PGSIG (Pasquill, 1961 and Gifford, 1960).

The former versions of CDM "slipped" the categories to account for urban effects on the dispersion. The inclusion of the various dispersion characterizations provides the user with both urban and rural dispersion schemes. Under user control is the specific curve to be applied to each of the stability categories of the input frequency function. The user specifies the initial dispersion for each stability category for use in the area source computatuins. The user specifies the power-law exponent and the central wind speed values to be employed for each stability category. Provision is made to model

pollutant removal by physical or chemical processes by a half-life decay that is user specified. Plume rise for the point sources can be calculated following the methods of Briggs (1969, 1971 and 1975) or using the methods of Holland (1953). Provision has been made to allow estimation of the effects of wind speed variation on the area-source effective release height as described by Turner and Novak (1978). The output format has been modified to enhance readability; concentration versus stability histograms have been added as an output option. Also new in this release is a default option to set input parameters for regulatory use.

The source code has been designed so that future enhancements can be readily implemented. For instance, the number of sources considered by the model can be modified by a global change within the code. Also, other dispersion schemes can be added to subroutine SIGMAZ with little difficulty.

SECTION 1

INTRODUCTION

CDM-2.0 is an enhanced version of CDM (Version 80247) affording the user increased control of the technical features to be employed in each modeling analysis. The user now controls the specification of the wind profile power-law exponents, the central wind speed values, the dispersion curves, and the mixing heights to be associated with each stability category. These were formerly defined by DATA statements in CDM and beyond user control. The plume rise algorithm has been modified to handle rise during stable conditions and to consider momentum-dominated plumes. Stack downwash can be modeled using either of two schemes -- Briggs (1974) or Bjorklund and Bowers (1982). Initial dispersion can be modeled as (1) a building effect, affecting sources with stack heights below 50 m, (2) as a buoyant plume-rise effect, as described by Pasquill (1976), or (3) joint building and buoyant rise effects. The user has the option of choosing among seven schemes for characterizing vertical dispersion downwind of the source. The output format has been modified to enhance readability and the concentration versus stability histogram has been added as an output option.

CDM-2.0 is applicable to locations with level or gently rolling terrain. The Gaussian plume hypothesis is the basis for the model. Pasquill and Meade (1958) first modified the Gaussian plume equation to estimate long-term average concentrations from a particular source using a wind direction frequency distribution. Expanding on Pasquill and Meade's initial work, Martin and Tikvart (TRW Systems Group, 1969; Martin and Tikvart, 1968; and Martin, 1971) developed AQDM (Air Quality Display Model). In their methodology, the frequency of occurrence of various possible combinations of wind direction, wind speed, and atmospheric stability are used to obtain long-term average concentrations from a multiple source grid. Calder (1971, 1977) formulated a model called CDM (Climatological Dispersion Model) which eventually superseded AQDM. Although similiar to AQDM in many respects, CDM has several distinct features. AQDM treats area sources via a modified virtual point source technique. In CDM, contributions from area sources are calculated by assuming the narrow plume hypothesis (Calder, 1971, 1977) and involve an upwind integration over the area sources. Holland's plume rise equation (Holland, 1953) is used in AQDM, while in CDM the user has a choice between Briggs' plume rise (Briggs, 1971) or Holland's equation. A power-law profile is used in CDM to extrapolate surface wind speeds to the source height. AQDM and CDM were two of six air quality dispersion models used to calculate annual (1969) sulfur dioxide and total suspended particulate matter for the New York Air Quality Control Region (Turner et al., 1972). Model-predicted concentrations were compared statistically with the measured values. The results indicate that CDM performed better than AQDM (i.e., errors in the means and maxima were smaller for CDM).

This document is divided into three parts, each directed to a different reader: managers, dispersion meteorologists, and computer specialists. The first four sections are aimed at managers and project directors who wish to evaluate the applicability of the model to their needs. Sections 5, 6, and 10 are directed toward dispersion meteorologists or engineers who are required to become familiar with the details of the model. Finally, Sections 7 through 10 are directed toward persons responsible for implementing and executing the program. A discussion of the default option is given in Appendix A.

SECTION 2

DATA-REQUIREMENTS CHECKLIST

CDM-2.0 requires data on user options, grid dimensions, sources, meteorology, receptors, and model calibration constants. The user must indicate whether the following options are to be employed for point source calculations:

- o Initial dispersion and/or buoyancy-induced dispersion,
- o Stack-tip downwash, and
- o Gradual plume rise.

Also to be indicated is whether the stability array data is divided into 16 or 36 wind-direction sectors. Additionally, there is a choice of one of seven dispersion schemes. Output options include area and point source concentration roses and concentration versus stability histograms at selected receptors.

Information required for each source includes the following:

- o Location (user units),
- o Area-source side length (m)
- o Average emission rate (g/sec) for both pollutants,
- o Daytime and nighttime emission rate ratios,
- o Source height (m),
- o Stack diameter (m),
- o Stack gas exit velocity (m/sec),
- o Stack gas temperature (EF, EC, or K), and
- o Decay half-life (hr).

Area-source side length is required for area sources; stack diameter, exit velocity, and exit temperature are pertinent to point sources only.

Meteorological data needed for the computations are:

- o Joint frequency function of wind direction, wind speed, and stability category,
- o Average wind speed (m/sec) representing each of six wind-speed categories,
- o Mean atmospheric temperature (EC),
- o Mixing heights (m) for each of six stability classes, and
- o Wind-profile exponents for each stability class.

The user has the option of inputting a joint frequency function based on 16 or 36 wind-direction sectors. The first wind sector of the joint frequency function must be centered on the wind direction azimuth of 0E.

The location of each receptor must be indicated. If available, the observed concentration of each pollutant can be supplied. Also the user has the option of specifying the height above ground (m) of all the receptors.

Calibration constants based on previous CDM-2.0 runs and on observed data can be provided and used to obtain adjusted concentration values.

SECTION 3

FEATURES AND LIMITATIONS

As noted previously, CDM-2.0 is an upgraded version of program CDM which was released in 1973. CDM-2.0 is a long-term (seasonal or annual) algorithm for evaluating the effects of multiple point and area sources in the near-field (within 25 km). The modeling region should consist of relatively flat terrain. The model includes the following computation features in common with CDM:

- Can handle up to 200 point sources and 2500 area sources,
- Unlimited number of receptors can be considered, and
- Optional use of Holland's equation (1953) for limiting plume rise.

It should be noted that the number of sources can be modified by a global change within the code. Optional output features common to both CDM and CDM-2.0 are point and area concentration roses at a set of user-specified receptors. The user can reduce output volume by just listing concentration results and not echoing the input data.

Modeling features added to CDM-2.0 include:

- Optional initial dispersion, buoyancy-induced dispersion, stack-tip downwash, and gradual plume rise;
- Choice of joint frequency function based on 16 or 36 wind direction sectors;
- Choice of one of seven dispersion parameter schemes;
- Optional output of concentration versus stability histograms at user-specified receptors; and
- Default option to set input parameters for regulatory use

The plume rise algorithm has been modified to handle rise during stable conditions and to consider momentum-dominated plumes.

Its limitations are as follows:

- Source emissions and meteorology should be uncorrelated,
- Variation in emission rate between adjacent area sources is assumed to be negligible,
- Terrain should be flat to gently rolling, and
- No consideration of chemical reactions or removal other than that which can be handled as a simple exponential decay.

It is assumed that one wind vector and one stability category are representative at any given time of the area being modeled.

Table 1 compares CDM-2.0 features to those of other long-term air quality models.

TABLE 1. A COMPARISON OF CDM-2.0 TO OTHER COMMONLY USED LONG-TERM AIR QUALITY MODELS.

X - used by model O - optional	CDM2.0	MPTER	CRSTER	VALLEY	ISC	CDM	
MODEL TYPE							
Gaussian		X	X	X	X	X	X
AVERAGING PERIOD							
Hour		O	X		O		
3-hour		O	X		O		
24-hour			O	X	O	O	
Annual	X	O	X	O	O	X	
TYPE OF SOURCES							
Single stack	X	X	X	X	X	X	
Multiple stacks	200	250	19[1]		50[2]		X[3]
200							
Area sources	2500			50[2]		X[3]	
2500							
RECEPTORS							
Number of	X[4]		180	180	112	360	X[4]
Cartesian coordinates		X			X	X	
Cartesian coordinates w/elevations	X	X			X		
Polar coordinates		X	X		X		
Polar coordinates w/ elevations			X	X	X	X	
METEOROLOGICAL DATA							

RAMMET preprocessor			X	X		X		
STAR file[5]	X			X	X	X		
User specified		X	O		X		O	X
POLLUTANT								
Non-reactive	X	X	X	X	X[6]		X	
Half-life	O	O	O	O	O	O		
PLUME RISE								
Stack-tip downwash		O	O	O		O		
Gradual plume rise		O	O	O	O	O	X	
Buoyancy-induced dispersion	O	O	O	O				
TERRAIN ADJUSTMENTS		O	O	O	O			

(1) Collocated stacks.

(2) Total of 50 point and/or area sources.

(3) Number of sources depends upon several input parameters.

(4) Unlimited.

(5) Note the difference in STAR file for VALLEY, ISC, CDM.

(6) Gravitational settling and dry deposition considered.

SECTION 4

BASIS FOR CDM-2.0

This section presents a brief narrative highlighting important aspects of the modeling approach. A detailed technical description, including equations, is provided in Section 5.

GAUSSIAN PLUME ORIGINS

CDM-2.0 is based upon the Gaussian plume hypothesis. Gaussian plume methodology assumes that pollutant concentrations from a continuously emitted plume are proportional to the emission rate, and are diluted by the wind at the point of emission at a rate inversely proportional to the wind speed. It is also assumed that the pollutant concentrations in the vertical near the source are closely described by Gaussian or normal distributions. Calder (1971, 1977) showed that under the special circumstance when emissions and meteorology can be treated as statistically independent, i. e., uncorrelated, that the long-term average concentration values can be estimated using the average emission values and the joint frequency function of meteorological conditions. In the methodology, the joint frequency function is assumed to be piece-wise constant in 22.5E (10E) wind sectors of a 16-point (36-point) compass. We assume that in practice (and certainly when large grid areas are used to specify the area-source emissions), the variations in emission rates between adjacent area sources can be disregarded. Then under the narrow plume hypothesis, the equations for computing the long-term average concentration contributions from the point sources and the area sources do not involve the crosswind dispersion parameter, but only the vertical dispersion parameter. The area-source contributions are determined by an integration over the upwind area sources. For this integration, an area-source emission rate (over the wind-sector width) is determined at various distances upwind from each receptor.

PLUME RISE

The user can choose between two methods of estimating plume rise: Briggs' plume rise (1969, 1971, and 1975) and Holland's equation (1953). The Briggs formulation treats both buoyancy-dominated and momentum-dominated rise. In Holland's equation, the value of the product of the average wind speed and the height of plume rise is used. This option permits no variation of the product with distance from the stack and the magnitude of the plume rise is at the discretion of the user.

DISPERSION ALGORITHMS

As an option the user can choose one of seven schemes for characterizing vertical dispersion downwind of the source. These include the following:

- Briggs-rural (Gifford, 1976),
- Briggs-urban (Gifford, 1976),
- Brookhaven National Laboratory (Singer and Smith, 1966),
- Klug (Vogt, 1977),
- St. Louis (Vogt, 1977),
- PGCDM (Busse and Zimmerman, 1973), and
- PGSIG (Pasquill, 1961 and Gifford, 1960).

The above algorithms are functions of downwind distance and atmospheric stability. Dispersion curves and equations for each of the schemes are presented in the next section.

SECTION 5

TECHNICAL DESCRIPTION

This section expands on concepts mentioned briefly in Section 4. The mathematical formulation of the physical processes simulated by CDM-2.0 are presented here. Equations are shown in their final form (i.e., without derivations); however, references are provided for those readers interested in the details.

METEOROLOGICAL PARAMETERS

Joint Frequency Function

The joint frequency function (also known as STability ARray) is required as input for the model. This function gives the joint frequency of occurrence of a wind-direction sector, a wind-speed class, and a stability category index. The user has the option of providing a joint frequency function based on 16 wind-direction sectors (each sector is 22.5E) or 36 sectors (each sector is 10E). It is required that the first wind sector be centered on the wind direction azimuth of 0E. There are 576 entries in the joint frequency function table for 16 wind-direction sectors (i.e., 16 wind-direction sectors, 6 wind-speed classes, and 6 stability classes). If the user's joint frequency function is based on a 36 point wind rose, then there are 1296 entries in the table.

The relationship between the Pasquill stability classes and those used in CDM-2.0 is shown in Table 2.

TABLE 2. RELATIONSHIP BETWEEN PASQUILL STABILITY CLASSES AND THOSE USED IN CDM-2.0

Pasquill stability class	CDM-2.0 stability index
A	1
B	2
C	3
D, day	4
D, night	5
E	6
F	7

The seven classes result from neutral stability being separated into daytime and nighttime conditions. Although CDM-2.0 recognizes 7 distinct categories, the joint frequency function is assumed to be comprised of only 6 stability classes. The user indicates the dispersion curve associated with each of the stability categories of his joint frequency data via variables ICP and ICA. These and other input parameters are described in Section 8.

The user must supply the central wind speed values for a height of 10 m above ground level for each of the six speed categories; typically that is the harmonic average wind speed. Wind speed intervals assumed in the National Climatic Center (NCC) STAR summaries are shown in Table 3, along with appropriate central wind speeds.

TABLE 3. NCC STAR SPEED INTERVALS AND CENTRAL WIND SPEEDS

Wind speed class	NCC speed interval (knots)	Central wind speeds (m/sec)
1	0 to 3	1.50 *
2	4 to 6	2.46
3	7 to 10	4.47
4	11 to 16	6.93
5	17 to 21	9.61
6	> 21	12.52

* Light winds reported in the first wind speed class are rounded up to 1.50 m/sec. Operational wind instruments are designed for durability and also to withstand exposure to strong, gusty airflow. For these reasons, most wind sensors have a high starting speed, which can lead to the erroneous reporting of light winds as calms (Truppi, 1968).

Wind Profile

Wind speed generally increases with height above the surface, and this increase depends on both surface roughness and atmospheric stability. A power-law profile of the form

$$U(z) = U_R(z/10)^p \quad (1)$$

is used by CDM-2.0 to approximate this increase. The wind speed at a height z above the ground is U(z); U_R is the wind speed measured at the anemometer height (10 m above the ground); and p is a function of stability. The user supplies the wind-profile exponents, p, for each stability class. Suggested wind-profile exponents are shown in Table 4. For a more detailed discussion of wind profiles, the reader may refer to Irwin (1979).

TABLE 4. WIND PROFILE EXPONENTS FOR TWO SURFACE ROUGHNESSES

	Stability class					
	A	B	C	D	E	F
Urban p	0.15	0.15	0.20	0.25	0.30	0.30
Rural p	0.07	0.07	0.10	0.15	0.35	0.55

Mixing Height

The magnitude of the mixing height undergoes considerable diurnal, seasonal, and annual variation. It is impractical to account for all such variations in detail. Some recognition is given to changes in the magnitude of the mixing height by assigning an appropriate value to each stability category. The user must choose an appropriate relationship between mixing height and stability category. One possible parameterization is given in Table 5.

TABLE 5. MIXING HEIGHTS BASED ON STABILITY CATEGORY

Stability category	Mixing height, meters
A	$3\bar{L}/2$
B	$\bar{L}$
C	$\bar{L}$
D,day	$\bar{L}$
D,night	$(\bar{L} + L_{min})/2$
E - F	L_{min}

In Table 5, $\bar{L}$ is the climatological mean value of the mixing height as tabulated by Holzworth (1972) and L_{min} is the nocturnal mixing height.

CONCENTRATION FORMULAS

The average concentration due to area sources, C_A, at a particular receptor is given by

$$C_A = (N/2\pi) \int_0^{\infty} [\sum_{k=1}^{N} q_k(\rho) \sum_{\ell=1}^{6} \sum_{m=1}^{6} \phi(k,\ell,m)\, S(\rho,z;U_{\ell},P_m)]\, d\rho, \qquad (2)$$

where,

N = number of wind-direction sectors (i.e., 16 or 36),
k = index identifying wind-direction sector,
$q_k(\rho)$ = $\int Q(\rho,\theta,)d\theta$ for the k sector,
$Q(\rho,\theta)$ = emission rate of the area source per unit area,
ρ = distance from the receptor to an infinitesimal area source,
θ = angle relative to polar coordinates centered on the receptor,
ℓ = index identifying the wind-speed class,
m = index identifying the stability category,
$\phi(k,\ell,m)$ = joint frequency function,
$S(\rho,z;U_{\ell},p_m)$ = dispersion function defined in Eqs. 4 and 5,
z = height of receptor above ground level,
U_{ℓ} = representative wind speed,
P_m = stability category.

For point sources, the average concentration due to n point sources, $\bar{C}_P$, is given by

$$\bar{C}_P = (N/2\pi) \sum_{n=1}^{n} \sum_{\ell=1}^{6} \sum_{m=1}^{6} [\phi(k_n,\ell,m)\, G_n\, S(\rho_n,z;U_{\ell},P_m)]/\rho_n, \qquad (3)$$

where
k_n = wind sector appropriate to the nth point source,
G_n = emission rate of the nth point source,
ρ_n = distance from the receptor to the nth point source.

The dispersion function, $S(\rho,z,;U_{\ell},P_m)$, is defined as

$$S(\rho,z;U_{\ell},P_m) = 2/((2\pi)^{1/2} U_{\ell}\sigma_z)[\exp\{-(1/2)[(z-H)/\sigma_z]^2 \} + \exp\{-(1/2)[(z+H)/\sigma_z]^2\}]\exp[-0.692\rho/(U_{\ell}T_{1/2})], \qquad (4)$$

if F_z < 0.8L and as

$$S(D,z;U_R,P_m) = (1/U_R)\exp[-0.692D/(U_R T_{1/2})], \qquad (5)$$

if F_z > 0.8L. New terms in Eqs. 4 and 5 are defined as follows:

F_z = vertical dispersion parameter, i.e., the standard deviation of the pollutant concentration in the vertical plane,
H = effective stack height of source distribution, i.e., the average height of area source emissions in the kth wind direction sector at radial distance from the receptor,
L = the mixing height,
$T_{1/2}$ = assumed half-life of pollutant (hr).

The possibility of pollutant removal by physical or chemical processes is included in the program by the decay expression, $\exp[-0.692D/(U_R T_{1/2})]$. The total concentration for the averaging period is the sum of concentrations of the point and area sources for that averaging period.

Computational procedures for area source contributions differ among the sector-average models in UNAMAP. For instance, Valley and ISCLT consider area sources as virtual point sources (Burt, 1977; Bowers et al., 1979). This computational method differs from the procedure used in CDM-2.0, which is discussed next.

Suppose that receptor R is located within the grid array. The first step in the program is to determine the distance from the receptor to the farthest corner of the grid array. This distance, D_M, is taken as the upper limit of the integral $q_k(D)$ in Eq. 2.

An angular integration, using the trapezoidal rule, is carried out numerically. This integration determines $q_k(D)$ at various increments of D, as indicated in Table 6.

TABLE 6. INCREMENTS OF INTEGRATION

Upwind range (m)	Increment*
$0 < D < 2500$	DELR
$2500 < D < 5000$	2CDELR
$5000 < D \leq D_M$	4CDELR

* The value of DELR is controlled by the user (see Section 8).

The integration over D (see Eq. 2) follows next and is also accomplished using the trapezoidal rule. The integration over D extends beyond the boundary of the grid system but no additional contribution to the concentration occurs since the source density is zero.

In the case where the receptor lies outside the emission grid array, the nearest distance, D_m, to the grid boundary as well as the maximum distance, D_M , is found. The lower limit to the integral over D is then D_m and the upper limit is D_M. Evaluating the integral from D_m instead of from zero results in reduced computer time.

STACK DOWNWASH

The user has the option of applying either of two stack-tip downwash algorithms: Briggs' (1974) or Bjorklund and Bowers' (1982).

Briggs Stack Downwash

The physical height is modified following Briggs (1974, p. 4). The modified physical stack height, h', is found from

$$h' = \begin{cases} h + 2[(V_s/U) - 1.5]D_s & \text{for } V_s < 1.5U \\ h & \text{for } V_s \geq 1.5U \end{cases} \tag{6}$$

where h is the physical stack height (meters), V_s is stack gas velocity (m/sec), and D_s is inside stack-top diameter (meters). If the user chooses this downwash algorithm, then h' is used throughout the remainder of the plume height computation.

Bjorklund and Bowers Stack Downwash

The effects of stack-tip downwash can also be simulated by applying a correction factor to the estimated plume rise. According to Bjorklund and Bowers (1982) the stack-tip downwash correction factor, f, is defined by

$$f = \begin{cases} 1 & \text{for } U \leq V_s/1.5 \\ (3V_s - 3U)/V_s & \text{for } V_s/1.5 < U < V_s \\ 0 & \text{for } U \geq V_s \end{cases} \tag{7}$$

This correction factor accounts for the effects of downwash in the lee of stacks during periods when the wind speed at the stack height is greater than or equal to 0.67 times the stack gas exit velocity. It is not used (i.e., f = 1) for stacks with Froude numbers less than 3.0. The Froude number, Fr, is the ratio of the inertial force to the force of gravity for a given fluid flow. Briggs (1969) defines the Froude number for stack gas releases as

$$Fr = V^2_s /\{g[(T_s - T_a)/T_a]D_s\}. \tag{8}$$

PLUME RISE

The user has a choice between two methods of estimating plume rise: Briggs' algorithm (1969, 1971, and 1975) and Holland's equation (1953).

Briggs Plume Rise

Neutral-Unstable Momentum Rise--

Regardless of the atmospheric stability, neutral-unstable momentum rise is calculated. The plume rise is calculated from Briggs' (1969, p. 59) Eq. 5.2:

$$\Delta H = 3D_sV_s/U. \tag{9}$$

Briggs (1969) suggests that this equation is most applicable when V_s/U is greater than 4. Since momentum rise occurs quite close to the point of release, the distance to final rise is set equal to zero.

Neutral-Unstable Buoyancy Rise--

The value of the Briggs buoyancy flux parameter, $F(m^4/s^3)$, is needed for computing the distance to final rise and the plume rise. The following equation is equivalent to Briggs' (1975, p. 63) Eq. 12:

$$F = (gV_sD^2_s\Delta T)/(4T_s) \tag{10}$$

where $\Delta T = T_s - T_a$, T_s is stack gas temperature (K), and T_a is ambient air temperature (K).

For situations where $T_s \geq T_a$, buoyancy is assumed to dominate. The distance to final rise x_f (in kilometers) is determined from the equivalent of Briggs' (1971, p. 1031) Eq. 7, and the distance to final rise is assumed to be 3.5x*, where x^* is the distance at which atmospheric turbulence begins to dominate entrainment. For F less than 55,

$$x_f = 0.049F^{5/8} \tag{11}$$

For F equal to or greater than 55,

$$x_f = 0.119F^{2/5}. \tag{12}$$

The plume rise, ΔH (in meters), is determined from the equivalent of the combination of Briggs' (1971, p. 1031) Eqs. 6 and 7. For F less than 55,

$$\Delta H = 21.425F^{3/4}/U. \tag{13}$$

For F equal to or greater than 55,

$$\Delta H = 38.71F^{3/5}/U. \tag{14}$$

If the neutral-unstable momentum rise (previously calculated from Eq. 9) is higher than the neutral-unstable buoyancy rise calculated here, momentum rise applies and the distance to final rise is set equal to zero.

Stability Parameter--

For stable situations, the stability parameter s is calculated from the equation (Briggs, 1971, p. 1031):

$$s = g(\partial\theta/\partial z)/T_a. \tag{15}$$

As an approximation, for stability class E (or 6), $\partial\theta/\partial z$ is taken as 0.02 K/m, and for stability class F (or 7), $\partial\theta/\partial z$ is taken as 0.035 K/m.

Stable Momentum Rise--

When the stack gas temperature is less than the ambient air temperature, it is assumed that the plume rise is dominated by momentum. The plume rise is calculated from Briggs' (1969, p. 59) Eq. 4.28:

$$\Delta H = 1.5[(V_s^2 D_s^2 T_a)/(4T_s U)]^{1/3} s^{-1/6}. \tag{16}$$

This is compared with the value for neutral-unstable momentum rise (Eq. 9) and the lower of the two values is used as the resulting plume height.

Stable Buoyancy Rise--

For situations where $T_s \geq T_a$, buoyancy is assumed to dominate. The distance to final rise (in kilometers) is determined by the equivalent of a combination of Briggs' (1975, p. 96) Eqs. 48 and 59:

$$x_f = 0.0020715Us^{-1/2}. \tag{17}$$

The plume rise is determined by the equivalent of Briggs' (1975, p. 96) Eq. 59:

$$H = 2.6[F/(UCs)]^{1/3}. \tag{18}$$

The stable buoyancy rise for calm conditions (Briggs, 1975, pp. 81-82) is also evaluated:

$$)H = 4F^{1/4}\ s^{-3/8}. \tag{19}$$

The lower of the two values obtained from Eqs. 18 and 19 is taken as the plume rise.

If the stable momentum rise is higher than the stable buoyancy rise calculated here, momentum rise applies and the distance to final rise is set equal to zero.

Gradual Plume Rise--

If the user exercises the gradual plume rise option and the distance upwind from receptor to source x (in kilometers) is less than the distance to final rise, the equivalent of Briggs' (1971, p. 1030) Eq. 2 is used to determine plume rise:

$$H = (160F^{1/3}h^{2/3})/U. \tag{20}$$

This height is used only for buoyancy-dominated conditions; should it exceed the final rise for the appropriate condition, the final rise is substituted instead.

Holland's Equation

Alternatively, plume rise can be estimated by Holland's equation (1953). The user supplies the product of the average wind speed and the height of plume rise (U)H) via input variable SA (see Section 8). Holland's equation for UC)H is as follows:

$$UC)H = D_s\ V_s\ \{1.5 + 0.00268p_a\ [(T_s - T_a\ )/T_s\ ]D_s\ \}, \tag{21}$$

where p_a is the atmospheric pressure in millibars (the other variables are defined above). This equation frequently underestimates plume rise (Turner, 1970 and Johnson et al., 1976). Holland (1953) suggested that a value between 1.1 and 1.2 times the computed plume rise from Eq. 9

should be used for unstable conditions and a value between 0.8 and 0.9 times the computed plume rise should be used for stable conditions. This is accommodated in CDM-2.0 by adjusting the plume rise as,

$$)H(final) = (SA/U)(1.4 - 0.1CICP), \qquad (22)$$

where SA is defined above and ICP is an array of values input by the user to define the dispersion curve to be associated with each stability category.

DISPERSION ALGORITHMS

As noted previously, the concentration formulas are independent of F_y but dependent on F_z, the vertical dispersion parameter. This results from the assumption in CDM-2.0 (and all other climatological dispersion models) that there are no variations of the wind direction frequency function within a wind-direction sector.

The user has the option of choosing among seven vertical dispersion parameter schemes; these are:

- o Briggs-rural (Gifford, 1976),
- o Briggs-urban (Gifford, 1976),
- o Brookhaven National Laboratory (Singer and Smith, 1966),
- o Klug (Vogt, 1977),
- o St. Louis (Vogt, 1977),
- o PGCDM (Busse and Zimmerman, 1973), and
- o PGSIG (Pasquill, 1961 and Gifford, 1960).

The F_z curves for each of the above dispersion algorithms are described as follows. The Pasquill stability categories have been used here for convenience. The BNL and St. Louis dispersion algorithms defined four curves and thus assumed different turbulence typing methods (Singer and Smith, 1966; Vogt, 1977). The PGCDM dispersion algorithm was included among the options since it is the scheme used by CDM, CDM-2.0's predecessor. The dispersion curves D1 and D2 in the PGSIG scheme represent adiabatic and subadiabatic neutral conditions, respectively. Lacking suitable temperature profile data for the lower 100 meters of the atmosphere, day and night may be substituted as criteria for adiabatic and subadiabatic lapse rates, respectively. Nighttime is typically defined as one hour prior to sunset to one hour after sunrise.

The dispersion curves can be approximated by one of the following equations:

$$F_z = aD/(1 + bD)^c \text{ and} \quad (23)$$

$$F_z = aD^b \ , \quad (24)$$

where a, b, and c are constants and D is the downwind distance. Eq. 23 is used to simulate the Briggs-rural and -urban schemes; the power-law formula shown in Eq. 24 represents the BNL, Klug, St. Louis, PGCDM, and PGSIG algorithms. Parameters a, b, and c are provided in Tables 7, 8, and 9.

CALIBRATION OF COMPUTED CONCENTRATION

If the calibration constants of the linear expression

$$C' = A + BC, \quad (25)$$

where

C' = calibrated concentration,
A, B = calibration constants, and
C = computed concentration,

are known, they may be entered into the program and used to obtain a calibrated concentration. The calibration constants are determined from regression analysis of observed air quality and the computed concentrations produced by the model. Thus, at least one initial run of the model must be made without the calibration feature. Once the model has been run to obtain computed concentrations, a regression procedure may be followed using computed versus observed concentrations. After finding the desired constants, calibrated concentrations can be obtained on subsequent operations of the model.

GRID SYSTEM AND AREA EMISSIONS

A rectangular grid array of uniform-sized squares is used to overlay the region of interest. The main purpose of this grid is to catalogue the emission inventory by area sources. There is some flexibility in the size of the grid squares in that the computer program accepts information on emissions from squares whose sides have lengths which are integer multiples of the length of the side of the basic square. Thus, if the basic square has a length s, emission information for a larger square whose side has a length, say 4s, is accepted by the model and distributed uniformly into 16 basic squares.

TABLE 7. CONSTANTS FOR VERTICAL DISPERSION EQUATIONS USED BY FIVE DISPERSION SCHEMES

Dispersion algorithm	Eq	Const	Pasquill Stability Class A	B	C	D, day	D, night	E	F
Briggs-rural	23	a	0.2000	0.1200	0.0800	0.0600	0.0600	0.0300	0.0160
		b	0.0000	0.0000	0.0002	0.0015	0.0015	0.0003	0.0003
		c	1.0000	1.0000	0.5000	0.5000	0.5000	1.0000	1.0000
Briggs-urban	23	a	0.2400	0.2400	0.2000	0.1400	0.1400	0.0800	0.0800
		b	0.0010	0.0010	0.0000	0.0003	0.0003	0.0015	0.0015
		c	-0.5000	-0.5000	1.0000	0.5000	0.5000	0.5000	0.5000
BNL	24	a	0.4000	0.4000	0.3300	0.2200	0.2200	0.0600	0.0600
		b	0.9100	0.9100	0.8600	0.7800	0.7800	0.7100	0.7100
Klug	24	a	0.0170	0.0720	0.0760	0.1400	0.1400	0.2170	0.2620
		b	1.3800	1.0210	0.8790	0.7270	0.7270	0.6100	0.5000
St. Louis	24	a	0.0790	0.0790	0.1310	0.9100	0.9100	1.9300	1.9300
		b	1.2000	1.2000	1.0460	0.7020	0.7020	0.4650	0.4650

TABLE 8. CONSTANTS FOR THE VERTICAL PARAMETER EQUATION USED IN THE PGCDM SCHEME *

Stability class	100 to 500 a	100 to 500 b	500 to 5000 a	500 to 5000 b	5000 to 50000 a	5000 to 50000 b
A	0.0383	1.2812	0.0002539	2.088	0.2539E-3	2.0886
B	0.1393	0.9467	0.04936	1.1137	0.4936E-1	1.1137
C	0.1120	0.9100	0.1014	0.9260	0.1154	0.9109
D, day	0.0856	0.8650	0.2591	0.6869	0.7368	0.5642
D, night	0.0856	0.8650	0.2591	0.6869	0.7368	0.5642
E	0.0818	0.8155	0.2527	0.6341	1.2969	0.4421
F	0.0545	0.8124	0.2017	0.6020	1.5763	0.3606

* Constants are to be used in conjunction with Eq. 24.

TABLE 9. CONSTANTS FOR THE VERTICAL DISPERSION PARAMETER EQUATION USED IN THE PGSIG SCHEME *

Stability class	Distance (km)	Constants a	b
A	< 0.1	122.80	0.9447
	0.1 - 0.15	158.08	1.0542
	0.15 - 0.2	170.22	1.0932
	0.2 - 0.25	179.52	1.1262
	0.25 - 0.3	217.41	1.2644
	0.3 - 0.4	258.89	1.4094
	0.4 - 0.5	346.75	1.7283
	> 0.5	453.85	2.1166
B	< 0.2	90.673	0.93198
	0.2 - 0.4	98.483	0.98332
	> 0.4	109.300	1.09710
C		61.141	0.91465
D, day		33.504	0.8098
D, night	< 0.3	34.459	0.86974
	0.3 - 1	32.093	0.81066
	1 - 3	32.093	0.64403
	3 - 10	33.504	0.60486
	10 - 30	36.650	0.56589
	> 30	44.053	0.51179
E	< 0.1	24.260	0.83660
	0.1 - 0.3	23.331	0.81956
	0.3 - 1	21.628	0.75660
	1 - 2	21.628	0.63077
	2 - 4	22.534	0.57154
	4 - 10	24.703	0.50527
	10 - 20	26.970	0.46713
	20 - 40	35.420	0.37615
	> 40	47.618	0.29592
F	< 0.2	15.209	0.81558
	0.2 - 0.7	14.457	0.78407
	0.7 - 1	13.953	0.68465

1 - 2	13.953	0.63227
2 - 3	14.823	0.54503
3 - 7	16.187	0.46490
7 - 15	17.836	0.41507
15 - 30	22.651	0.32681
30 - 60	27.074	0.27436
> 60	34.219	0.21716

4444444444444444444444444444444444444444444444444444444444444444444444444444U

* Constants are to be used in conjunction with Eq. 24.

The origin of the overlay grid is located in the lower left-hand corner of the array with the X-axis pointing toward the east and the Y-axis pointing toward the north. With respect to the map coordinates of the region, the origin of the grid array is to be located at some suitably chosen point in the lower left-hand section of the region under consideration. The length of the side of a square is expressed in meters. However, the map coordinates can be expressed in any suitable units, say, thousands of feet or kilometers. The magnitude of the length of a square depends on how many squares are needed in the emission inventory of a region. For example, CDM-2.0 is dimensioned at present to handle 2500 area sources (and 200 point sources); thus, the grid square dimension must be chosen such that the limiting criteria of 2500 area sources is not exceeded. Computation can be performed for any number of receptor points.

OTHER CONSIDERATIONS

Initial Dispersion

The value of initial F_z for point sources due to building effects is modeled as a function of the height above ground of the stack, h. Table 10 summarizes the relationship between initial F_z and stack height.

TABLE 10. RELATIONSHIP BETWEEN INITIAL F_z AND STACK HEIGHT

444444444444444444444444444444444444444444444444444444444444444444444444444444U

Stack height, h (m)	Initial F_z (m)

444444444444444444444444444444444444444444444444444444444444444444444444444444U

$0 < h \leq 20$	30
$20 < h \leq 50$	$50 - h$
$50 < h$	0

444444444444444444444444444444444444444444444444444444444444444444444444444444U

For area sources, initial values of F_z which account for building effects are user defined for each stability class.

Buoyancy-Induced Dispersion

For strongly buoyant plumes, entrainment as the plume ascends through the ambient air contributes to vertical spread. Pasquill (1976) suggests that this induced dispersion, F_{zb}, can be approximated by the plume rise divided by 3.5. The effective dispersion can then be determined by adding variances:

$$F_{ze} = (F_{zb}^2 + F_z^2)^{1/2}, \tag{26}$$

where F_{ze} is the effective dispersion, and F_z is the dispersion due to ambient turbulence levels.

Effluent Rise for Area Sources

CDM-2.0 can consider changes in effective height with wind speed for area sources. The input area source height, H_a, is assumed to be the average physical height of the area source plus the effluent rise with a wind speed of 5 m/sec. The user specifies the fraction, f_e, of the input height that represents the physical height, h. This fraction is the same for all area sources in the inventory. The relationship among H_a, f_e, and h is as follows:

$$h = f_e H_a. \tag{27}$$

If $f_e = 1$, there is no rise and the input height is the effective height for all wind speeds. For any wind speed, U, the rise is assumed to be inversely proportional to U and is determined by

$$)H = (5/U)(H_a - h); \tag{28}$$

the effective height is then

$$H = h +)H. \tag{29}$$

SECTION 6

EXAMPLE PROBLEM

The example problem contained in Section 6 of the complete version of the User's Guide has been intentionally omitted from this abridged version.

SECTION 7

COMPUTER ASPECTS OF THE MODEL

This section discusses CDM-2.0 from a software design and programming perspective, and is intended to give the reader a general knowledge of the computational system, rather than a detailed description of each subroutine. The overall structure of the program, a brief description of each subroutine, and the general processing flow are given here. The overall system flow, the input/output media, data flow, and alternative processing are also provided.

SYSTEM FLOW

An overview of the system will be beneficial to the reader. Input data requirements are contained in either one or two files depending on the user assignment of variable IRD (see Section 8). Output is in two forms: printed output and card image output, usually going to a disk file. Card-image records containing the calculated concentrations at each receptor are written for use in computer programs that analyze information produced by CDM-2.0. As discussed in Section 5, a regression program must be applied to obtain calibration constants. Additionally, the disk file output can be used with user-supplied plot routines to obtain isopleth plots of concentration.

In addition to the records containing the concentrations from area and point sources, further output may be produced if the NROSE option is used (see Section 8). If NROSE is specified as greater than zero, additional records are written. Concentration versus stability histograms and concentration roses for both pollutants and both source types are provided.

The input/output (I/O) units used by CDM-2.0 are summarized in Table 13.

TABLE 13. INPUT/OUTPUT UNITS USED BY CDM-2.0

FORTRAN unit	I/O unit	Mode	Contents
5	Disk	input	Program control and input data (record types 1-3)
IRD*	Disk	input	Program control and input data (record types 4-18)
IWR*	Printer or disk	output	Output listing
IPU*	Disk or magnetic tape	output	Concentration data tape

* See Section 8.

STRUCTURE OF CDM-2.Ø

CDM-2.0 consists of a main routine and nine subroutines. Program control data, meteorological data, and source information are read by subroutine CLINT. The main routine reads receptor data until an end-of-file is encountered and then execution is terminated. With the exception of one warning message generated by CALQ, all output is performed by the main routine or by subroutine CLINT. Brief descriptions of the main program and subroutines follow.

CDM-2.0 -- The main program first calls subroutine CLINT to obtain input information other than receptor data. Information on receptors is read directly by the main program which then directs the concentration calculations through subroutine calls to CALQ, AREA, and POINT. Output concentrations are formatted for printer display and are also written to a file for use in regression and/or plotting.

CLINT -- This subroutine is called by the main routine to read program control data, meteorological data, and source information. It also echoes input according to user specification. It calls subroutine VIRTX.

CALQ -- Called by the main program, subroutine CALQ computes the area source vector for each direction sector. The area source vector contains emission rates for two pollutants and release heights at various upwind distances.

AREA -- This subroutine is called by the main routine to calculate concentrations due to area sources. It calls subroutine SIGMAZ.

POINT -- Subroutine POINT is called by the main routine to calculate concentrations due to point sources. It calls subroutines VIRTX, STDW, and SIGMAZ.

DFAULT -- This second level subroutine sets some of the user-defined options; see Appendix A for further discussion. It is called by subroutine CLINT if the user turns on the default option.

PLRISE -- Called by subroutine POINT, this module calculates plume rise according to the methods of Briggs (1969, 1971, and 1975).

VIRTX -- This second level subroutine is called by CLINT and POINT; it computes the virtual distance applicable to the user-specified initial dispersion. VIRTX calls SIGMAZ to estimate vertical dispersion.

STDW -- This subroutine is called by POINT to estimate stack downwash.

SIGMAZ -- This subroutine is called by AREA, POINT, and VIRTX to calculate the vertical dispersion parameter. The user can choose among seven different schemes.

NON-STANDARD FEATURES

The PARAMETER statement, which is used in the main program, is not an ANSI FORTRAN statement, and hence may not be available in the user's FORTRAN compiler. As PARAMETER allows constants to be referenced by symbolic names, it facilitates the updating of programs in which the only changes between compilations are in the values of certain constants. In CDM-2.0, the PARAMETER statement initializes the following variables:

NPTS - number of point sources,
NQLIM - number of upwind integration steps allowed,
NASE - number of east-west area-source grid squares,
NASN - number of north-south area-source grid squares,

which in turn are used to dimension several arrays. If the user's compiler does not support the PARAMETER statement, the variables NPTS, NQLIM, NASE, and NASN must be hardcoded. The best way to do this is to perform global changes using a text editor.

SECTION 8

INPUT DATA PREPARATION

RECORD INPUT SEQUENCE

There are 18 record types read by CDM-2.0. Six of these are free format input, eight are fixed format, three are of user-specified format, and one is a blank record. While the free format is easy to use, care should be taken to ensure that every variable is given a value in the correct order. Also each variable should be separated by a comma and should conform to the variable name type (integer or real). Table 14 lists the record types and input associated with each record. A brief description of each input variable is given in Table 15 with the appropriate units. Under the "Format" column of Table 15, FF represents free format and US indicates user-specified format.

TABLE 14. SUMMARY OF RECORD TYPES FOR INPUT DATA.

Record type	Input Description	Format type	Input unit	Calling subroutine
1	HEADNG - run title	Fixed	5	CLINT
2	NSO2,PNAME	Fixed	5	CLINT
3	AROS,PROS,IRUN,NLIST,IRD, IWR,IPU,CA,CB	Fixed	5	CLINT
4	N1636,NP50,NPDH,NSTDW, NGRAD,FAC,RCEPTZ,KELVIN, NDEF	Free	IRD	CLINT
5	KLOW,ICA	Free	IRD	CLINT
6	KHIGH,ICP	Free	IRD	CLINT
7	DELR,RAT,CV,XG,YG,TOA, TXX	Fixed	IRD	CLINT
8	DINT,YD,YN,SZA,GB	Fixed	IRD	CLINT
9	UE	Free	IRD	CLINT
10	U	Free	IRD	CLINT
11	H	Free	IRD	CLINT
12	FMETEO	Fixed	IRD	CLINT
13	F	FMETEO	IRD	CLINT
14	FSOURC	Fixed	IRD	CLINT
15	X,Y,TX,S1,S2,SH,D,	FSOURC	IRD	CLINT

	VS,T,SA			
16	Blank Sentinel Card (End of source input)	--	IRD	CLINT
17	FRECPT	Fixed	IRD	MAIN
18	RX,RY,KPX(9),KPX(10), NROSE	FRECPT	IRD	MAIN

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TABLE 15. RECORD INPUT SEQUENCE FOR CDM-2.0

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Record type, Variable	Column	Format	Variable description (units)
Record type 1			
HEADNG	1-80	20A4	80-character description or title of model run
Record type 2			
NSO2	1- 1	I1	Pollutant number for SO_2 = 0, SO_2 not considered = 1, pollutant 1 is SO_2 = 2, pollutant 2 is SO_2
PNAME	5-12	2A4	Names of two pollutants to be modeled (e.g., SO_2, TSP)
Record type 3			
AROS	1- 8	2A4	Alphanumeric area rose output identification
PROS	9-16	2A4	Alphanumeric point rose output identification
IRUN	17-21	I5	User-defined run identification
NLIST	22-26	I5	Control for printed output > 0, echo set-up information, meteorology, and list concentration results = 0, echo set-up information, meteorology, source, and list concentration results < 0, list concentration results only
IRD	27-31	I5	FORTRAN logical unit number-read
IWR	32-36	I5	FORTRAN logical unit number-print
IPU	37-41	IS	FORTRAN logical unit number-punch

TABLE 15. (CONT.) RECORD INPUT SEQUENCE FOR CDM-2.0

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Record type, Variable	Column	Format	Variable description (units)
CA	42-59	2F9.0	Intercepts of calibration for both pollutants (Fg/m^3)
CB	60-77	2F9.0	Slopes of calibration for both pollutants
Record type 4			
N1636	---	FF	Number of wind directions used in the meteorological joint frequency function (16 or 36)
NP50	---	FF	Initial dispersion option # 0, no action taken on point sources with release heights below 50 m > 0, initially dispersed as described in Section 5
NPDH	---	FF	Buoyancy-induced dispersion option # 0, no action taken > 0, include buoyancy-induced dispersion effects (Pasquill, 1976) in point source dispersion
NSTDW	---	FF	Stack downwash option < 0, Bjorklund, Bowers (1982) stack downwash used = 0, no action taken > 0, Briggs (1974) stack downwash considered
NGRAD	---	FF	Gradual plume rise option = 0, no action taken > 0, gradual plume rise used
FAC	---	FF	Effluent rise for area sources See Section 5 for description.

RCEPTZ	---	FF	Height above ground of all receptors (meters)

TABLE 15. (CONT.) RECORD INPUT SEQUENCE FOR CDM-2.0

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Record type, Variable	Column	Format	Variable description (units)
KELVIN	---	FF	Units flag for stack gas temperature < 0, EF = 0, EC > 0, K
NDEF	---	FF	Default option = 0, no action taken > 0, implement default option (see Appendix A)
Record type 5			
KLOW	---	FF	Dispersion parameter scheme for area sources
ICA	---	FF	Array of six values defining dispersion curves (as defined by KLOW) to be used for the six stability categories summarized in the joint frequency function
Record type 6			
KHIGH	---	FF	Dispersion parameter scheme for point sources
ICP	---	FF	Array of six values defining dispersion curves (as defined by KHIGH) to be used for the six stability categories summarized in the joint frequency function
Record type 7			
DELR	1- 6	F6.0	Radial increment (meters)
RAT	7-12	F6.0	Length of basic emission grid square (user units)
CV	13-18	F6.0	Conversion factor (m/user units) CVCRAT = emission grid interval in meters

TABLE 15. (CONT.) RECORD INPUT SEQUENCE FOR CDM-2.0

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Record type, Variable	Column	Format	Variable description (units)
XG	19-24	F6.0	East-west map coordinate of the southwest corner of theemission grid array (user units)
YG	25-30	F6.0	North-south map coordinate of the southwest corner of the emission grid array (user units)
TOA	31-36	F6.0	Mean atmospheric temperature (EC)
TXX	37-42	F6.0	Width of the basic emission grid square (meters)
Record type 8			
DINT	1- 6	F6.0	Number of intervals used to integrate over a 22.5E or 10E sector. Maximum value is 20; minimum is 2.
YD	7-12	F6.0	Ratio of the daytime emission rate to the average 24-hour emission rate
YN	13-18	F6.0	Ratio of the nighttime emission rate to the average 24-hour emission rate
SZA	19-54	6F6.0	Initial F_z for area sources (meters)
GB	55-66	2F6.0	Decay half-life for the two pollutants (hours)
Record type 9			
UE	---	FF	Array of six values defining wind profile exponents to be associated with the six stability categories summarized in the joint frequency function

TABLE 15. (CONT.) RECORD INPUT SEQUENCE FOR CDM-2.0

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Record type, Variable	Column	Format	Variable description (units)
Record type 10			
U	---	FF	Array of six values defining wind speeds at 10 m to be associated with the six wind speed categories summarized in the joint frequency function (m/sec)
Record type 11			
HL	---	FF	Array of six values defining mixing heights to be associated with the six stability categories summarized in the joint frequency function (meters)
Record type 12			
FMETEO	1-64	16A4	Format statement, including beginning and ending parentheses, for the meteorological joint frequency function. User note: CDM format was (7X,6F7.0)
Record type 13*			
F(i,j,k)	---	US	Meteorological joint frequency function; i = index for stability class j = index for wind speed class k = index for wind direction
Record type 14			
FSOURC	1-64	16A4	Format statement, including beginning and ending parentheses, for the source inventory. User note: CDM format was (F6.0,2F7.0,2F8.0,F7.0, F5.0,2F7.0,F5.0)
Record type 15[#]			
X	---	US	East-west coordinate of source (user units)
Y	---	US	North-south coordinate of source (user units)

TABLE 15. (CONT.) RECORD INPUT SEQUENCE FOR CDM-2.0

Record type, Variable	Column	Format	Variable description (units)
TX	---	US	Width of area source (meters). Leave blank for point sources.
S1	---	US	Emission rate of pollutant 1 (g/sec)
S2	---	US	Emission rate of pollutant 2 (g/sec)
SH	---	US	Source height (meters)
D	---	US	Stack diameter (meters) Leave blank for area sources.
VS	---	US	Exit velocity (m/sec) Leave blank for area sources.
T	---	US	Stack gas temperature Leave blank for area sources. User selected units (see record type 4).
SA	---	US	Plume rise option # 0, Briggs plume rise > 0, Holland's equation. Enter product of plume rise and wind speed (m^2/sec)
Record type 16			
--	---	--	This is a blank record which follows the source data. It is used to test for the end of the source data and must not be left out.
Record type 17			
FRECPT	1-64	16A4	Format statement, including beginning and ending parentheses, for the receptors. User note: CDM format was (2F8.0,14X,I4,3X,I4,I5).
Record type 18]			
RX	---	US	East-west coordinate of the receptor (user units)

RY	---	US	North-south coordinate of the receptor (user units)

TABLE 15. (CONT.) RECORD INPUT SEQUENCE FOR CDM-2.0

Record type, Variable	Column	Format	Variable description (units)
KPX9	---	US	Observed concentration of pollutant 1 at the receptor, if known (Fg/m^3)
KPX10	---	US	Observed concentration of pollutant 2 at the receptor, if known (Fg/m^3)
NROSE	---	US	Option for pollutant concentration roses > 0, print concentration roses # 0, no concentration roses

FF = free format; US = user-specified format

* If N1636 = 16 there are 96 records of this type; if N1636 = 36 there are 216 records of this type.

There are as many of this record type as there are sources.

] There are as many of this record type as there are receptors.

INTRICACIES OF THE DATA

Most of the input data are straightforward and typical of the kind of information required for Gaussian models. However, there are some input variables which require additional explanation to ensure proper value assignment.

Record Type 2

CDM-2.0 calculates concentrations for two pollutants in a single execution. Therefore, the user is asked to input two pollutant names, two sets of calibration constants, and two emission rates, one for each of the two pollutants modeled. In this record, the user is asked to provide two names for the pollutants. These two names, which are each four characters in length, are subsequently used in the output as labels. It is important that the order used in this record for array variable PNAME is followed for array variables CA and CB in record type 3 and variables S1 and S2 in record type 15.

Variable NSO2 informs the program which of the pollutants if any is SO_2. Within the program, SO_2 requires special processing depending on the options exercised. If NSO2 = 0, then the program assumes that SO_2 will not be run. If NSO2 = 1, then pollutant 1 is assumed to be SO_2; if NSO2 = 2, then pollutant 2 is assumed to be SO_2.

<u>Record Type 3</u>

AROS and PROS are alphanumeric arrays to identify the output record for the area and point concentration roses. In defining these two arrays it is important to keep in mind that area and point concentration roses are provided for both pollutants. AROS and PROS might be input as follows:

```
AROS(1) = A P1          PROS(1) = P P1
AROS(2) = A P2          PROS(2) = P P2
```

The first two characters refer to the source type (i.e., A for area and P for point) and the last two characters refer to pollutant (i.e., P1 for pollutant 1 and P2 for pollutant 2).

If the calibration feature of CDM-2.0 is not used, the value of the intercept (CA) and slope (CB) should be specified as 0 and 1, respectively. This results in the calibrated concentration identical to the computed value. Note that CA and CB are two entry arrays for the two pollutants being modeled.

<u>Record Type 4</u>

For point sources, CDM-2.0 allows user selection of both initial dispersion due to building effects and buoyancy-induced dispersion. The user should verify that simultaneous selection of these options is appropriate for the particular modeling situation.

Variable NDEF is the default option switch. This feature is designed as a convenience to the user with the aim of avoiding inadvertent errors in setting the options. By exercising the default option, several features are automatically set thus overriding other user-input selections. Specifics of the default option are summarized in Appendix A.

<u>Record Types 5 and 6</u>

The user-specified dispersion parameter scheme for area and point sources is indicated through variables KLOW and KHIGH, respectively. Table 16 lists the dispersion algorithm and its corresponding value of KLOW or KHIGH.

TABLE 16. VALUES OF KLOW OR KHIGH AND THEIR CORRESPONDING DISPERSION PARAMETER SCHEMES

KLOW or KHIGH	Dispersion parameter scheme
1	Briggs-rural (Gifford, 1976)
2	Briggs-urban (Gifford, 1976)
3	BNL (Singer and Smith, 1966)
4	Klug (Vogt, 1977)
5	St. Louis (Vogt, 1977)
6	PGCDM (Busse and Zimmerman, 1973)
7	PGSIG (Pasquill, 1961 and Gifford, 1960)

Although CDM-2.0 recognizes seven distinct stability categories, the meteorological joint frequency function is assumed to be comprised of only six classes. The specification of the values for arrays ICA and ICP is, in part, a function of the manner in which the joint frequency function is formulated, and these arrays are a function of the dispersion parameter scheme selected. In the original CDM, the PGCDM dispersion parameter scheme was employed. The urban effects were modeled by "slipping" the curves, i.e. using a curve other than that which would ordinarily be used in a rural situation. With the enhancements incorporated in CDM-2.0, one can select either to accommodate urban effects as was done in CDM or, one can select either the Briggs-urban or the St. Louis schemes. An example should clarify their use.

Assume we have specified KLOW and KHIGH to be 7 (PGSIG scheme). Suppose NCC's Day-Night STAR program is used to generate the joint frequency function; this summary includes the following stability categories: A, B, C, D-day, D-night, and nighttime stable (i.e., a combination of Pasquill classes E and F). Array variables ICP and ICA would be defined as 1, 2, 3, 4, 5, and 6 for modeling a rural situation. If one wanted to account for urban effects by "slipping" the categories, as was done by CDM, then ICP would be 1, 2, 3, 5, 5, 5, and ICA would be 1, 1, 2, 3, 5, 5. However, if the joint frequency function is formulated using categories A, B, C, D, E, and F, then ICP and ICA are input as: 1, 2, 3, 5, 6, and 7 for a rural situation. Mixing height is not affected by array variables ICP and ICA since it is linked to the six stability categories summarized in the joint frequency function.

Record Type 7

A potential error in the area source integration algorithm is radial skipover (Brubaker et al., 1977). This occurs when the area source size is smaller than the sampling interval, n DELR, where n = 1, 2, or 4 (see Section 5). It is easy to see that radial skipover can be minimized by keeping DELR small. However, not only is CPU time increased with decreasing DELR but also CDM-2.0 is limited presently to 100 radial arcs. Thus the use of smaller DELR may result in the termination of the radial integration due to array size restrictions before the far edge of the emission grid is reached with the corresponding omission of a significant part of the total area source contribution.

The easiest way to explain the emission grid is by a practical example. Suppose that an emission inventory exists with the smallest emission square 5000 feet on a side and all coordinates are given in terms of feet. In this instance, the basic emission grid square is 5000 feet on a side and thus RAT is 5000. CV is 0.3048 (i.e., 1 ft = 0.3048 m); TXX is 1524 (i.e., 5000 ft = 1524 m); and XG, YG, are in feet. Also, all source and receptor coordinates are expressed in feet (map coordinates).

Record Type 8

Another source of error in the area source integration is angular skipover. The area source is skipped over by the sampling points when the angular width of the area source is smaller than the width of a sector. Obviously, the potential for angular skipover is reduced if the area source inventory is described using large (say 5 km or larger) grid squares. For a detailed inventory employing area-source squares with side lengths of 1 km, Brubaker et al. (1977) suggests using DINT = 10 with a wind direction sector of 22.5E to reduce the likelihood of angular skipover. DINT = 4 is probably sufficient with a 10E wind-direction sector (i.e., N1636 = 36).

Record Type 11

HL is an array variable containing six values which define mixing heights (in meters) associated with the six stability categories summarized in the joint frequency function. The user must decide on an appropriate relationship between mixing height and stability category.

One possible scheme is shown in Table 5.

Dispersion from sources with effective release heights above the mixing height is not assumed to reach the receptors. If the mixing height is set to zero for a particular stability, then no contributions from any of the sources would occur (during that particular stability). If the user believes that unlimited mixing is the appropriate condition for a particular stability, then the mixing height (for that stability category) should be specified as a very large value (say 9999.9 m).

SECTION 9

EXECUTION OF THE MODEL AND SAMPLE TEST

EXECUTION

(This section is intentionally omitted from the abridged version)

ERROR MESSAGES AND REMEDIAL ACTION

CDM-2.0 can generate nine error messages and two warning messages. An error message results in program termination while a warning message allows execution to continue. Table 18 lists each message, along with its description and suggested corrective action.

TABLE 18. CDM-2.0 ERROR/WARNING MESSAGES AND CORRECTIVE ACTION

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MESSAGE (1):	*** VALID VALUES FOR NSO2 ARE 0, 1, OR 2. *** USER INPUT NSO2 = nnnn *** EXECUTION TERMINATED.
DESCRIPTION:	NSO2 must be set to 0, 1, or 2. Any other value will result in program termination.
ACTION:	Modify input stream so that NSO2 is equal to 0, 1, or 2 and resubmit the job.

S))
))))))))

MESSAGE (1):	*** VALID VALUES FOR N1636 ARE 16 OR 36. *** USER INPUT N1636 = nnnn *** EXECUTION TERMINATED.
DESCRIPTION:	The meteorological joint frequency function can only consist of 16 or 36 wind-direction sectors. The user tried to input a value different from 16 or 36.
ACTION:	Modify the input stream so that N1636 is equal to 16 or 36 and make sure that the number of wind direction sectors in the joint frequency function agrees with the value given by N1636.

S))
))))))))

MESSAGE (1):	*** VALID VALUES FOR FAC RANGE FROM 0 TO 1. *** USER INPUT FAC = xxx.xx *** EXECUTION TERMINATED.
DESCRIPTION:	FAC must be between 0 and 1, inclusive. The user tried to input a value outside that range.

ACTION: Modify input stream so that FAC is between 0 and 1, inclusive.

S))
))))))))

MESSAGE (1):

```
*** VALID VALUES OF KLOW RANGE FROM 1 TO 7.
*** USER TRIED TO INPUT KLOW = nnn
*** EXECUTION TERMINATED.
```

DESCRIPTION: KLOW must be between 1 and 7, inclusive. The user tried to input a value outside that range.

TABLE 18. (CONT.) CDM-2.0 ERROR/WARNING MESSAGES AND CORRECTIVE ACTION

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ACTION: Modify input stream so that KLOW is between 1 and 7, inclusive.

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MESSAGE (1):
*** VALID VALUES FOR ICA RANGE FROM 1 TO 7.
*** USER TRIED TO INPUT ICA(i) = nnnn
*** EXECUTION TERMINATED.

DESCRIPTION: Values in the array ICA must be between 1 and 7, inclusive. The user tried to input a value outside that range.

ACTION: Modify input stream so that all the values in the array ICA are between 1 and 7, inclusive.

))

MESSAGE (1):
*** VALID VALUES FOR KHIGH RANGE FROM 1 TO 7.
*** USE INPUT KHIGH = nnnn
*** EXECUTION TERMINATED.

DESCRIPTION: KHIGH must be between 1 and 7, inclusive. The user tried to input a value outside that range.

ACTION: Modify input stream so that KHIGH is between 1 and 7, inclusive.

))

MESSAGE (1):
*** VALID VALUES FOR ICP RANGE FROM 1 TO 7.
*** USER INPUT ICP(i) = nnnn
*** EXECUTION TERMINATED.

DESCRIPTION: Values in the array ICP must be between 1 and 7, inclusive. The user tried to input a value outside that range.

ACTION: Modify input stream so that all the values in the array ICP are between 1 and 7, inclusive.

))

MESSAGE (1):
*** THE PRODUCT OF RAT AND CV MUST EQUAL TXX.
*** THE VALUES PROVIDED BY THE USER DO NOT
*** CONFORM TO THIS RELATIONSHIP.
*** EXECUTION TERMINATED.

DESCRIPTION: The quantities RAT, CV, and TXX are related by the following equation: TX = RATCCV. However, the user-supplied quantities do not relate in the prescribed manner.

ACTION: Modify input stream so that the quantities meet the above-mentioned relationship.

))
))))))))

MESSAGE (1): *** VALID VALUES FOR DINT RANGE FROM 2 TO 20.
*** USER INPUT DINT = xxx.x
*** EXECUTION TERMINATED.

DESCRIPTION: DINT must be between 2 and 20, inclusive. The user tried to input a value outside that range.

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ACTION:	Modify input stream so that DINT is between 2 and 20, inclusive.

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MESSAGE (2):	NOTE: AREA SOURCE WITH X COORD xxxxxxx.xx AND Y COORD yyyyyyy.yy VIOLATES AREA SOURCE ARRAY LIMITS. AREA SOURCES MUST LIE ENTIRELY WITHIN A xxxxxxxx.xx BY xxxxxxxx.xx METER SQUARE WITH SOUTHWEST CORNER AT THE USER-DEFINED ORIGIN (XG,YG). THIS SOURCE WILL NOT BE INCLUDED IN THIS CALCULATION.
DESCRIPTION:	The area source emission grid may not be larger than 50 grid squares in either the x or the y direction, this limit being determined by the dimensions of various arrays defined within the computer program. This limit, together with the user-specified size of a basic grid square (TXX), imposes a limit to the total size of the emission grid. A test is made to see that each area source falls within the boundaries of the grid. It was determined the area source mentioned in the warning message lies partially or wholly outside the grid boundaries. As indicated in the message, the calculation proceeds but the area source in violation is omitted from the inventory.
ACTION:	Adjust the location of the origin (XG,YG) or the size of the basic emission grid square (TXX) such that all area sources are within the boundaries of the grid. Alternatively, the dimensions could be appropriately increased to accommodate the area source inventory.

))

MESSAGE (2):	WARNING: MORE THAN 100 ARCS ARE REQUIRED FOR CALCULATION OF AREA CONTRIBUTION. AREA SOURCES BEYOND xxx.x KM ARE NOT INCLUDED IN THIS CALCULATION.
DESCRIPTION:	As discussed in Section 5, the area source algorithm evaluates the average emission rate on a series of arcs centered on the receptor of interest. No more than 100 arcs are used, this limit, together with the user-supplied radial

integration step, DELR, imposes an upper limit to the distance to which the area source calculations are taken. If there are area sources beyond this range, they are not included in the calculations.

TABLE 18. (CONT.) CDM-2.0 ERROR/WARNING MESSAGES AND CORRECTIVE ACTION

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ACTION:	The integration step, DELR, should be modified such that all area sources are included in the calculation. Alternatively, the user could increase the number of integration steps allowed.

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(1) Error message -- execution terminated.

(2) Warning message -- execution continues.

SECTION 1Ø

INTERPRETATION OF OUTPUT

NOTE: Discussion of printed input and output has been deleted in the abriged version.

The printed output of CDM-2.0 consists of four parts: set-up information, meteorology, source inventory, and concentration results. The set-up information, meteorology, and source inventory are optionally provided (see variable NLIST of record type 5 in Table 15). The format of the card image output is given in Table 21 for ease of interpretation.

TABLE 21. FORMAT OF CARD IMAGE OUTPUT.

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Record type, Variable	Column	Format	Variable description (units)
Record type 1			
RX	1-10	F10.2	X map coordinate of receptor (user units)
RY	11-20	F10.2	Y map coordinate of receptor (user units)
IRUN	21-25	I5	Run identification number
--	26	--	Card identifier
KPX(1)	27-30	I4	Concentration contribution from area sources for the first pollutant (Fg/m^3)
KPX(2)	31-34	I4	Concentration contribution from area sources for the second pollutant (Fg/m^3)
KPX(3)	35-38	I4	Concentration contribution from point sources for the first pollutant (Fg/m^{3}3)
KPX(4)	39-42	I4	Concentration contribution from point sources or the second pollutant (Fg/m^3)
KPX(5)	43-45	I4	Total concentration for the first pollutant (Fg/m^3)

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TABLE 21. FORMAT OF CARD IMAGE OUTPUT.

Record type, Variable	Column	Format	Variable description (units)
KPX(6)	46-50	I4	Total concentration for the second pollutant (Fg/m^3)
KPX(7)	51-54	I4	Calibrated total concentration for the first pollutant (Fg/m^3)
KPX(8)	55-58	I4	Calibrated total concentration for the second pollutant (Fg/m^3)
KPX(9)	59-62	I4	Observed concentration for the first pollutant (Fg/m^3)
KPX(10)	63-66	I4	Observed concentration for the second pollutant (Fg/m^3)
Record type 2*			
AROS	1- 4	A4	Identifier indicating area source contribution for the first pollutant
APAR	5-46	6F7.1	Area source contribution by stability class for the first pollutant (Fg/m^3)
KPX(37)	47-54	I8	X map coordinate of receptor multiplied by 100 to remove decimals (user units)
KPX(38)	55-62	I8	Y map coordinate of receptor multiplied by 100 to remove decimals (user units)
Record type 3*			
PROS	1 - 4	A4	Identifier indicating point source contribution for the first pollutant
PPAR	5-46	6F7.1	Point source contribution by stability class for the first pollutant (Fg/m^3)

TABLE 21. FORMAT OF CARD IMAGE OUTPUT.

4444444444444444444444444444444444444444444444444444444444444444444444444444

Record type, Variable	Column	Format	Variable description (units)
KPX(37)	47-54	I8	X map coordinate of receptor multiplied by 100 to remove decimals (user units)
KPX(38)	55-62	I8	Y map coordinate of receptor multiplied by 100 to remove decimals (user units)
Record type 4*			
--	---	---	Same as record type 2 for the second pollutant
Record type 5*			
--	---	---	Same as record type 3 for the second pollutant
Record type 6*#			
AROS	1- 4	A4	Identifier indicating area source contribution for the first pollutant
KPX	5-44	8I5	Area source contribution by wind direction starting at north and rotating clockwise (μg/m^3)
RX	45-52	I8	X map coordinate of receptor multiplied by 100 to remove decimals (user units)
RY	53-60	I8	Y map coordinate of receptor multiplied by 100 to remove decimals (user units)
Record type 7*#			
--	---	---	Same as record type 6 for the second pollutant
Record type 8*#			
PROS	1- 4	A4	Identifier indicating point source contribution for the first pollutant

TABLE 21. FORMAT OF CARD IMAGE OUTPUT.

444444444444444444444444444444444444444444444444444444444444444444444444444444

Record type, Variable	Column	Format	Variable description (units)
KPX	5-44	8I5	Point source contribution by wind direction starting at north and rotating clockwise (Fg/m^3)
RX	45-52	I8	X map coordinate of receptor multiplied by 100 to remove decimals (user units)
RY	53-60	I8	Y map coordinate of receptor multiplied by 100 to remove decimals (user units)
Record type 9*#			
--	---	---	Same as record type 8 for the second pollutant

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* Records written only if NROSE > 0.

\# If N1636 = 16 there are two records of this type; if N1636 = 36 there are four records of this type.

REFERENCES

Bjorklund, J. R. and J. F. Bowers. 1982. User's Instructions for the SHORTZ and LONGZ Computer Programs, Vols. I and II. EPA-903/9-82-004A and B (NTIS Accession Numbers PB83-146 092 and PB83-146 100). U. S. Environmental Protection Agency, Middle Atlantic Region III, Philadelphia, PA.

Bowers, J. F., J. R. Bjorklund, and C. S. Cheney. 1979. Industrial Source Complex (ISC) Dispersion Model User's Guide. EPA-450/4-79-030, U. S. Environmental Protection Agency, Research Triangle Park, NC 27711. 360 pp.

Briggs, G. A. 1969. Plume Rise, USAEC Critical Review Series. TID-25075, National Technical Information Service, U. S. Department of Commerce, Springfield, VA 22161. 81 pp.

Briggs, G. A. 1971. Some Recent Analyses of Plume Rise Observation. In: Proceedings of the Second International Clean Air Congress, H. M. Englund and W. T. Berry (eds.), Academic Press, New York. pp. 1029-1032.

Briggs, G. A. 1974. Diffusion Estimation for Small Emissions. In: ERL, ARL USAEC Report ATDL-106. U. S. Atomic Energy Commission, Oak Ridge, TN. 59 pp.

Briggs, G. A. 1975. Plume rise predictions. In: Lectures on Air Pollution and Environmental Impact Analysis, D. A. Haugen (ed.), Amer. Meteor. Soc., Boston, MA. pp. 59-111.

Brubaker, K. L., P. Brown, and R. R. Cirillo. 1977. Addendum to User's Guide for Climatological Dispersion Model. EPA-450/3-77-015, U. S. Environmental Protection Agency, Research Triangle Park, NC 27711. 134 pp.

Burt, E. W. 1977. Valley Model User's Guide. EPA-450/2-77-018, U. S. Environmental Protection Agency, Research Triangle Park, NC 27711. 112 pp.

Busse, A. D. and J. R. Zimmerman. 1973. User's Guide for the Climatological Dispersion Model. EPA-R4-73-024, U. S. Environmental Protection Agency, Research Triangle Park, NC 27711. 132 pp.

Calder, K. L. 1971. A Climatological Model for Multiple Source Urban Air Pollution. In: Proceedings of the Second Meeting of the Expert Panel on Air Pollution Modeling. NATO, Committee on the Challenges of Modern Society (CCMS). Paris, France, July 26-27. 33 pp.

Calder, K. L. 1977. Multiple-source plume models of urban air pollution - their general structure. Atmos. Environ. 11: 403-414.

Gifford, F. A., Jr. 1960. Atmospheric dispersion calculations using the generalized Gaussian plume model. Nucl. Saf. 2: 56-59.

Gifford, F. A., Jr. 1976. Turbulent diffusion typing schemes -- A review. Nucl. Saf. 17: 68-86.

Hanna, S. R., G. A. Briggs, and R. P. Hosker, Jr. 1982. Handbook on Atmospheric Diffusion. DOE/TIC-11223, National Technical Information Service, U. S. Department of Commerce, Springfield, VA 22161. 102 pp.

Holland, J. Z. 1953. A Meteorological Survey of the Oak Ridge Area. Atomic Energy Comm., Report ORO-99, Washington, DC. 584 pp.

Holzworth, G. C. 1972. Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States. Office of Air Programs Publication No. AP-101. U. S. Environmental Protection Agency, Research Triangle Park, NC. 118 pp.

Irwin, J. S. 1979. A theoretical variation of the wind profile law exponent as a function of surface roughness and stability. Atmos. Environ. 13: 191-194.

Johnson, W. B., R. C. Sklarew, and D. B. Turner. 1976. Urban Air Quality Simulation Modeling. In: Air Pollution, Part I -- Air Pollutants, Their Transformation and Transport, A. C. Stern (ed.), Academic Press, New York and London. pp. 503-562.

Martin, D. O. and J. A. Tikvart. 1968. A General Atmospheric Diffusion Model for Estimating the Effects of Air Quality of One or More Sources. APCA Paper 68-148, presented at 61st Annual APCA Meeting, St. Paul, Minnesota, June 1968.

Martin, D. O. 1971. An urban diffusion model for estimating long term average values of air quality. J. Air Poll. Contr. Assoc. 21: 16-19.

Pasquill, F. and P. J. Meade. 1958. A study of the average distribution of pollution around Staythorpe. Int. J. Air Poll. 1: 60-70.

Pasquill, F. 1961. The estimation of the dispersion of windborne material. Meteorol. Mag. 90: 33-49.

Pasquill, F. 1976. Atmospheric Dispersion Parameters in Gaussian Plume Modeling. Part II. Possible Requirements for Change in the Turner Workbook Values. EPA-600/4-76-030b, U. S. Environmental Protection Agency, Research Triangle Park, NC 27711. 44 pp.

Singer, I. A. and M. E. Smith. 1966. Atmospheric dispersion at Brookhaven National Laboratory. Int. J. Air Water Pollut. 10: 125 - 135.

Truppi, L. E. 1968. Bias introduced by anemometer starting speeds in climatological wind rose summaries. Mon. Wea. Rev. 96: 325-327.

Turner, D. B. 1970. Workbook of Atmospheric Dispersion Estimates. Office of Air Programs Publication No. AP-26 (NTIS-PB-191-482). U. S. Environmental Protection Agency, Research Triangle Park, NC 27711. 84 pp.

Turner, D. B., J. R. Zimmerman, and A. D. Busse. 1972. An evaluation of some climatological dispersion models. Presented at 3rd Meeting of the NATO/CCMS Panel on Modeling.

Turner, D. B. and J. H. Novak. 1978. User's Guide for RAM. Vol. I. Algorithm Description and Use. EPA-600/8-78-016a, U. S. Environmental Protection Agency, Research Triangle Park, NC. 60 pp.

TRW Systems Group. 1969. Air Quality Display Model. NTIS-PB-189-194, National Technical Information Service, U. S. Department of Commerce, Springfield, VA 22161.

Vogt, K. J. 1977. Empirical investigation of the diffusion of waste air plumes in the atmosphere. Nuclear Technology 34: 43-57.

APPENDIX A

DEFAULT OPTION

The default option is provided as a convenience to the user to help avoid inadvertent errors in setting the appropriate options. Exercising the default option (i.e., NDEF = 1) overrides other user-input selections and results in the following.

(1) Stack downwash according to Briggs (1974) is used.

(2) Briggs' plume rise (1969, 1971, and 1975) is used.

(3) Buoyancy-induced dispersion is exercised. For distances less than the distance to final rise, the gradual plume rise is used to determine the buoyancy-induced dispersion only.

(4) Final plume rise is used.

(5) To calculate vertical dispersion, the Briggs-urban scheme is selected.

(6) The joint frequency function is assumed to be comprised of the following six classes: A, B, C, D-day, D-night, and nighttime stable.

(7) Initial F_z values for area sources are 30 meters for all stability classes.

(8) Wind profile exponents are set to .15, .15, .20, .25, .25, and .30 for stabilities A, B, C, D-day, D-night, and stable cases respectively.

(9) Calibration intercepts and slopes are set to 0 and 1, respectively.

(10) A pollutant half-life of 4 hours for SO_2 is assumed and a half-life near infinity is assumed for all other pollutants.

Default values for all the affected variables are provided in Table A-1. For all other input variables not shown in Table A-1, CDM-2.0 assumes the values provided by the user.

TABLE A-1. VARIABLES AFFECTED BY THE DEFAULT OPTION

Record type	Variable	Default values
3	CA	0.0, 0.0
	CB	1.0, 1.0
4	NP50	-1
	NPDH	1
	NSTDW	1
5	KLOW	2
	ICA	1, 2, 3, 4, 5, 6
6	KHIGH	2
	ICP	1, 2, 3, 4, 5, 6
8	SZA	30., 30., 30., 30., 30., 30.
	GB	4.0 (for SO_2), 999999. (for all others)
9	UE	.15, .15, .20, .25, .25, .30
10	SA	-1